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(72) Inventor(s):
Mark Shuster
Lev Ring

(73) Proprietor(s):
Enventure Global Technology
(Incorporated in USA - Delaware)
16200-A Park Row, Houston, Texas 77084,
United States of America

(74) Agent and/or Address for Service:
Haseltine Lake
Redcliff Quay, 120 Redcliff Street, Bristol,
BS1 6HU, United Kingdom

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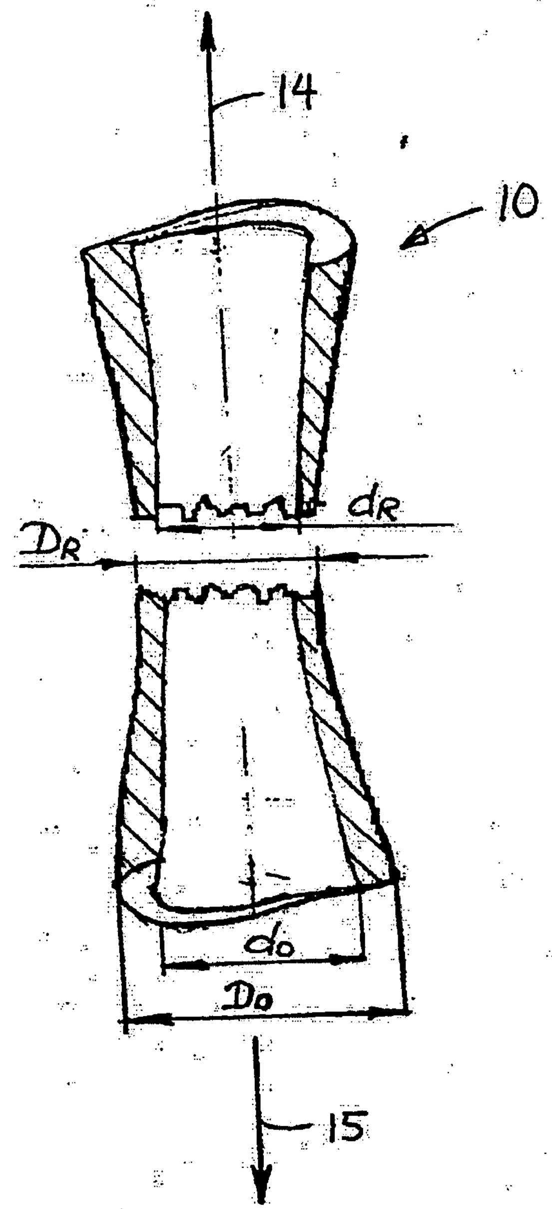

FIG. 1

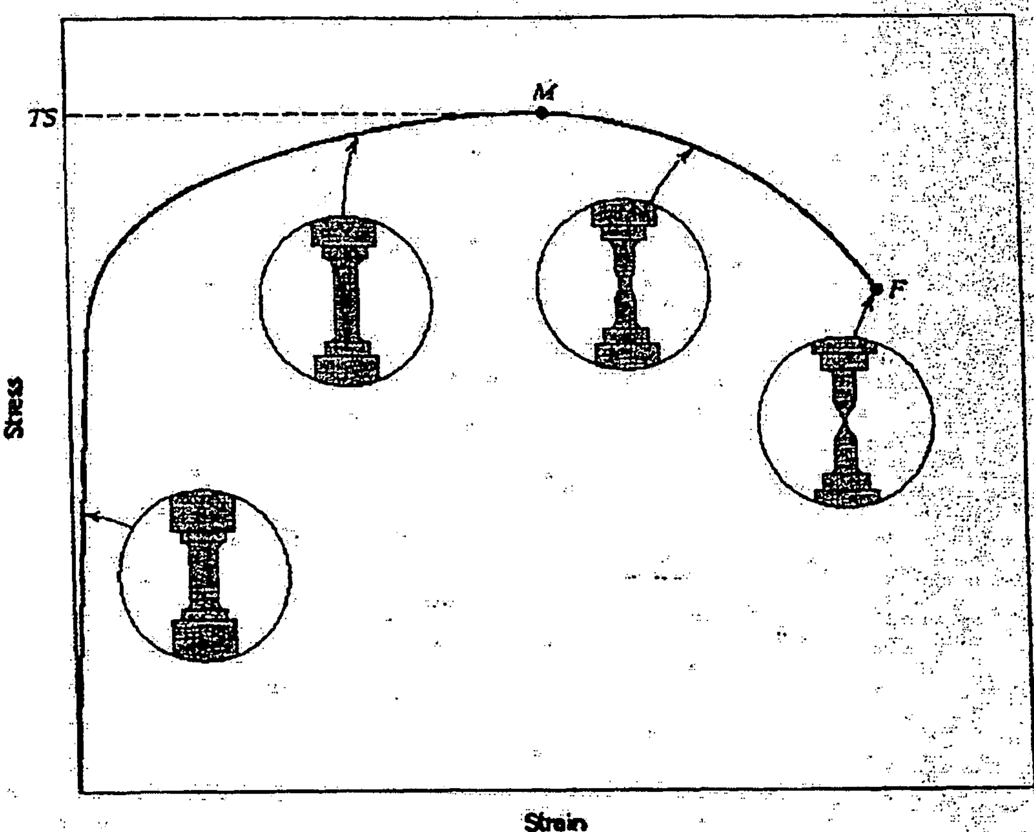

FIG. 2

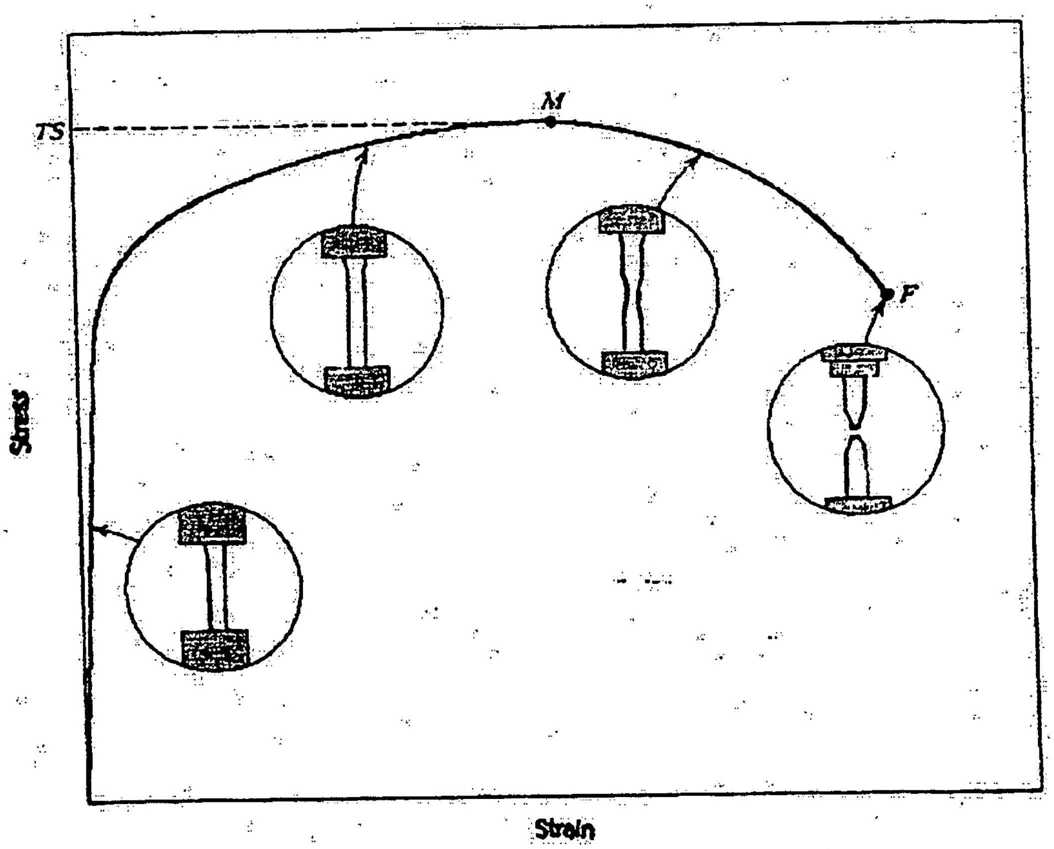

FIG. 3

PIPE FORMABILITY EVALUATION FOR EXPANDABLE TUBULARS

[0002] This invention relates generally to tubular steel well casing and more particularly to an expansion mandrel which reduces stress during expansion of the casing.

Background of the Invention

[0003] Solid tubular casing of substantial length is used as a borehole liner in downhole drilling. The casing is comprised of end-to-end interconnected segments of steel tubing to protect against possible collapse of the borehole and to optimize well flow. The tubing often reaches substantial depths and endures substantial pressures.

[0004] It is present practice to expand the steel tubing downhole by using a mandrel. This is a cold-working process which presents substantial mechanical challenges. This technology is known as solid expandable tubular (SET) technology. This cold-working process deforms the steel without any additional heat beyond what is present in the downhole environment.

[0006] An expansion cone, or mandrel, is used to permanently mechanically deform the pipe. The cone is moved through the tubing by a differential hydraulic pressure across the cone itself, and/or by a direct mechanical pull or push force. The differential pressure is pumped through an inner-string connected to the cone, and the mechanical force is applied by either raising or lowering the inner string.

[0007] Progress of the cone through the tubing deforms the steel beyond its elastic limit into the plastic region, while keeping stresses below ultimate yield. Expansions greater than 20%, based on pipe ID, have been accomplished. However, most applications using 4 1/4 - 13 3/8 inch (108-340 mm) tubing have required expansions less than 20%. The ID of the pipe expands to the same ID of the expansion mandrel, which is a function of expansion mandrel OD. Contact between cylindrical mandrel and pipe ID during expansion leads to significant forces due to friction. It would be beneficial to provide method for testing tubular members for suitability for the expansion process. It would also be beneficial to provide a method for selecting tubing or tubular members well suited for expansion.

[Next page – page 5]

Summary Of The Invention

[0008] According to the present invention, there is provided a method for selecting a tubular member for suitability for expansion on a basis comprising use of an expandability coefficient determined pursuant to a stress-strain test using axial loading in combination with one or more physical properties of the tubular member including the percentage by weight of carbon being no less than 0.02% and no more than 0.032%.

[0009] Preferably, the selection of the tubular member is further based on the Charpy energy being at least 90 ft-lbs at -4 °F (122J at –20°C).

[00010] Preferably, the selection of the tubular member is further based on the percentage by weight of niobium being between 0.015% and 0.12%.

[00011] Preferably, the selection of the tubular member is further based on the total concentration of niobium and titanium being less than 0.6% by weight.

[00012] Preferably, the selection of the tubular member is further based on each of the following ranges of weight percentages:

Si being from 0.009% to 0.30%;
Mn being from 0.10% to 1.92%;
P being from 0.004% to 0.07%;
S being from 0.0008% to 0.006%;
Al being up to 0.04%;
N being up to 0.01%;
Cu being up to 0.3%;
Cr being up to 0.5%;
Ni being up to 18%;
Nb being up to 0.12%;
Ti being up to 0.6%;
Co being up to 9%; and
Mo being up to 5%.

[00013] Preferably, the expandability coefficient is determined pursuant to a stress-strain test using axial loading comprising calculation of plastic strain ratio for obtaining the expansion coefficient pursuant to test results and using the formula:

$$f = \frac{\ln \frac{b_0}{b_k}}{\ln \frac{L_k b_k}{L_o b_o}} \qquad \text{Equation 1}$$

where,

f – expandability coefficient

bo & bk – initial and final tube area (inch^2)

Lo & Lk – initial and final tube length (inch)

B = (D^2-d^2)/4 – cross section tube area.

[00014] Preferably, the selection of the tubular member is further based on stress-strain properties in one or more directional orientations of the material, and/or Charpy V-notch impact value in one or more directional orientations of the material, and/or stress rupture burst strength, and/or stress rupture collapse strength, and/or strain-hardening exponent (n-value), and/or hardness and yield strength.

Brief Description of the Drawings

[0013] Fig. 1 depicts in a schematic fragmentary cross-sectional view along a plane along and through the central axis of a tubular member that is tested to failure with axial opposed forces.

[0014] Fig. 2 is a stress-strain curve representing values for stress and strain that may be plotted for solid specimen sample.

[0015] Fig. 3. is a schematically depiction of a stress strain curve representing values from a test on a tubular member according to an illustrative example of one aspect of the invention.

[0016] APPENDIX A to the present application provides schematic illustrations of pipe formability evaluation for expandable tubulars in several alternative illustrative embodiments.

Detailed Description of the Illustrative Embodiments

[0017] One of the problems of the pipe material selection for expandable tubular application is an apparent contradiction or inconsistency between strength and elongation. To increase burst and collapse strength, material with higher yield strength is used. The higher yield strength generally corresponds to a decrease in the fracture toughness and correspondingly limits the extent of achievable expansion.

[0018] It is desirable to select the steel material for the tubing by balancing steel strength with amount absorbed energy measure by Charpy testing. Generally these tests are done on samples cut from tubular members. It has been found to be beneficial to cut directional samples both longitudinally oriented (aligned with the axis) and circumferentially oriented (generally perpendicular to the axis). This method of selecting samples is beneficial when both directional orientations are used yet does not completely evaluate possible and characteristic anisotropy throughout a tubular member. Moreover, for small diameter tubing samples representative of the circumferential direction may be difficult and sometimes impossible to obtain because of the significant curvature of the tubing.

[0019] To further facilitate evaluation of a tubular member for suitability for expansion it has been found beneficial according to one aspect of the invention to consider the plastic strain ratio. One such ratio is called a Lankford value (or *r*-value) which is the ratio of the strains occurring in the width and thickness directions measured in a single tension test. The plastic strain ratio (*r* or Lankford - value) with a value of greater than 1.0 is found to be more resistant to thinning and better suited to tubular expansion. Such a Lankford value is found to be a measure of plastic anisotropy. The Lankford value *(r)* may be calculate by the Equation 2 below:

$$r = \frac{\ln\frac{b_o}{b_k}}{\ln\frac{L_k b_k}{L_o b_o}}$$ Equation 2

where,

r - normal anisotropy coefficient

bo & bk - initial and final width

Lo & Lk - initial and final length

[0020] However, it is time consuming and labor intensive for this parameter to be measured using samples cut from real parts such as from the tubular members. The tubular members will have anisotropic characteristics due to crystallographic or "grain" orientation and mechanically induced differences such as impurities, inclusions, and voids, requiring multiple samples for reliably complete information. Moreover, with individual samples, only local characteristics are determined and the complete anisotropy of the tubular member may not be determinable. Further some of the tubular members have small diameters so that cutting samples oriented in a circumferential direction is not always possible. Information regarding the characteristics in the circumferential direction has been found to be important because the plastic deformation during expansion of the tubular members occurs to a very large extent in the circumferential direction.

[0021] One aspect of the present invention comprises the development of a solution for anisotropy evaluation, including a kind of plastic strain ratio similar to the Lankford parameter that is measured using real tubular members subjected to axial loading.

[0022] Fig. 1 depicts in a schematic fragmentary cross-sectional view along a plane along and through the axis 12 of a tubular member 10 that is tested with axial opposed forces 14 and 15. The tubular member 10 is axially stretched beyond the elastic limit,

through yielding and to ultimate yield or fracture. Measurements of the force and the OD and ID during the process produce test data that can be used in the formula below to produce an expandability coefficient "f" as set forth in Equation 1 above. Alternatively a coefficient called a formability anisotropy coefficient *F(r)* that is function of the normal anisotropy Lankford coefficient *r* may be determined as in Equation 3 below:

$$F(r) = \frac{\ln\frac{b_o}{b_k}}{\ln\frac{L_k b_k}{L_o b_o}} \qquad \text{Equation 3}$$

F(r) - formability anisotropy coefficient

bo & bk - initial and final tube area (inch^2)

Lo & Lk - initial and final tube length (inch)

b = (D^2-d^2)/4- cross section tube area.

[0023] In either circumstance *f* or *F(r)* the use of this testing method for an entire tubular member provides useful information including anisotropic characteristics or anisotropy of the tubular member for selecting or producing beneficial tubular members for down hole expansion, similar to the use of the Lankford value for a sheet material.

[0024] Just as values for stress and strain may be plotted for solid specimen samples, as schematically depicted in Fig 2, the values for conducting a test on the tubular member may also be plotted, as depicted in Fig 3. On this basis the expansion coefficient *f* (or the formability coefficient *F(r)*) may be determined. It will be the best to measure distribution (Tensile-elongation) in longitudinal and circumferential directions simultaneously.

[0025] The foregoing expandability coefficient (or formability coefficient) is found to be useful in predicting good expansion results and may be further useful when used in

combination with one or more other properties of a tubular member selected from stress-strain properties in one or more directional orientations of the material, strength & elongation, Charpy V-notch impact value in one or more directional orientations of the material, stress burst rupture, stress collapse rupture, yield strength, ductility, toughness, and strain-hardening exponent (n - value), and hardness.

[0026] In several alternative illustrative embodiments, pipe formability evaluation for expandable tubulars is provided as described and illustrated in Appendix A to the present application.

[0027] Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

CLAIMS:

1. A method for selecting a tubular member for suitability for expansion on a basis comprising use of an expandability coefficient determined pursuant to a stress-strain test using axial loading in combination with one or more physical properties of the tubular member including the percentage by weight of carbon being no less than 0.02% and no more than 0.032%.

2. The method of claim 1 wherein selecting the tubular member is further based on the Charpy energy being at least 90 ft-lbs at -4 °F (122J at −20°C).

3. The method of one of claims 1 and 2 wherein selecting the tubular member is further based on the percentage by weight of niobium being between 0.015% and 0.12%.

4. The method of one of claims 1-3 wherein selecting the tubular member is further based on the total concentration of niobium and titanium being less than 0.6% by weight.

5. The method of one of claims 1-4 wherein selecting the tubular member is further based on each of the following ranges of weight percentages:

Si being from 0.009% to 0.30%;
Mn being from 0.10% to 1.92%;
P being from 0.004% to 0.07%;
S being from 0.0008% to 0.006%;
Al being up to 0.04%;
N being up to 0.01%;
Cu being up to 0.3%;
Cr being up to 0.5%;
Ni being up to 18%;
Nb being up to 0.12%;
Ti being up to 0.6%;
Co being up to 9%; and
Mo being up to 5%.

6. The method of claim 1, wherein the expandability coefficient is determined pursuant to a stress-strain test using axial loading comprising calculation of plastic strain ratio for obtaining the expansion coefficient pursuant to test results and using the formula:

$$f = \frac{1n\frac{b_0}{b_k}}{1n\frac{L_k b_k}{L_o b_o}} \qquad \text{Equation 1}$$

where,

f – expandability coefficient

bo & bk – initial and final tube area (inch^2)

Lo & Lk – initial and final tube length (inch)

B = (D^2-d^2)/4 – cross section tube area.

7. The method of claim 1, wherein the physical properties of the tubular member further comprise stress-strain properties in one or more directional orientations of the material, and/or Charpy V-notch impact value in one or more directional orientations of the material, and/or stress rupture burst strength, and/or stress rupture collapse strength, and/or strain-hardening exponent (n-value), and/or hardness and yield strength.